UNCLASSIFIED

AD NUMBER
AD814825
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; JAN 1967. Other requests shall be referred to Air Force Materials Laboratory, ATTN: MAAM, Wright-Patterson AFB, OH 45433.**
AUTHORITY
AFSC ltr dtd 2 Mar 1972

THIS PAGE IS UNCLASSIFIED

AD0 814 825

AFML-TR-66-392

DYNAMIC SUBCRITICAL CRACK GROWTH PROPERTIES OF DUPLEX ANNEALED Ti-8A1-1MO-1V AND MILL ANNEALED Ti-6A1-4V IN AN AIR AND CORROSIVE ENVIRONMENT

G. J. PETRAK

UNIVERSITY OF DAYTON RESEARCH INSTITUTE

TECHNICAL REPORT AFML-TR-66-392

JANUARY 1967

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (MAAM), Wright-Patterson Air Force Base, Ohio 45433.

AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

400 - March 1967 - CO192 - 27-627

DYNAMIC SUBCRITICAL CRACK GROWTH PROPERTIES OF DUPLEX ANNEALED Ti-8A1-1MO-1V AND MILL ANNEALED Ti-6A1-4V IN AN AIR AND CORROSIVE ENVIRONMENT

G. J. PETRAK

UNIVERSITY OF DAYTON RESEARCH INSTITUTE

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (MAAM), Wright-Patterson Air Force Base, Ohio 45433.

FOREWORD

This report was prepared by Gerald J. Petrak of the University of Dayton Research Institute with Richard G. Coy serving as Project Leader. The work was performed under USAF Contract AF 33(615)-1312 under Project No. 7381, "Materials Application," Task No. 738106, "Design Information Development." This work was performed under the direction of Mr. Sidney O. Davis, Air Force Materials Laboratory, Research and Technology Division, Project Engineer.

The testing was done utilizing facilities in the Materials Information Branch, Materials Applications Division, Air Force Materials Laboratory.

This report covers work conducted from July 1965 to March 1966.

The manuscript of this report was released by the author November 1966 for publication as an RTD Technical Report.

The author would like to acknowledge Mr. Sidney O. Davis and Nathan G. Tupper, Capt. USAF, Air Force Materials Laboratory for their support and technical advice.

This technical report has been reviewed and approved.

D. A. SHINN
Chief, Materials Information Branch
Materials Applications Division
Air Force Materials Laboratory

ABSTRACT

This program was conducted to determine the dynamic (fatigue) crack growth properties of two titanium alloys (Ti-8Al-1Mo-1V Duplex Annealed and Ti-6Al-4V Mill Annealed) at room temperature in an air and in a 3.5 percent NaCl environment. Dynamic crack growth versus cycles to failure was determined at two loading frequencies (40 cpm and 2 cpm) for the corrosive environment and at a 40 cpm loading frequency for the air environment. A comparison of the air and corrosive environment test data at the 40 cpm loading frequency shows a reduction in cyclic life when exposed to the 3.5 percent NaCl environment. Also a comparison of the corrosive environment test data at loading frequencies of 40 cpm and 2 cpm shows a reduction in cyclic life on both a time and a number of cycles to failure basis at the higher loading frequency.

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

SECTION I

INTRODUCTION

Titanium alloys have been selected as the main-candidate structural materials for the supersonic transport airplane and also for many military aircraft in some structural applications. These materials were selected because of their high strength-to-weight ratios at the expected operating temperatures. They were also selected for their good crack propagation resistance properties and apparent insensitivity to stress corrosion cracking at ambient and elevated temperatures. However, recent test results indicate that the titanium alloys are susceptible to stress corrosion cracking if a crack has been initiated in the material. (See References 1, 2, and 3). The resulting load carrying capability of the material under these conditions is considerably reduced. As a result of these findings, a number of Industry and Government organizations initiated programs to determine the corrosive crack growth resistance characteristics of selected titanium alloys in order to evaluate the degree of degradation of load-carrying properties. The objective of the AFML program was to determine crack growth curves under dynamic loading of fatigue precracked Ti-8Al-1Mo-1V and Ti-6Al-4V at room temperature in both air and salt water environments.

SECTION II

SPECIMENS

The tensile specimens and center-notched fracture toughness specimens were machined to the configuration shown in Figures 1 and 2, respectively. Dynamic crack growth specimens were identical to the fracture toughness specimens. All fracture toughness specimens and crack growth specimens were initially fatigue precracked at a frequency of 1600 cpm. These environmental crack growth or fatigue crack propagation specimens will be referred to as dynamic crack growth specimens throughout the remainder of this report to distinguish them from static crack growth, environmental fracture toughness, or precracked stress corrosion specimen terminology used by other investigators. The materials information as submitted by the supplier is shown in Table I. All specimens were machined with their longitudinal axis parallel to the rolling direction. Photomicrographs of the material, as received from the supplier, are shown in Figure 3.

TABLE I

MATERIALS DATA

Producer - Titanium Metals Corporation of America

Chemical Composition

Material	C	Fe	N	Al	V	Mo	H	O_2
Ti-8Al-1Mo-1V DA*	.023	.5	.015	7.8	1.0	1.0	.005	.09
Ti-6Al-4V MA**	Not available							

Mechanical Properties

Material	Ultimate PSI	Yield PSI	Elongation %
Ti-8Al-1Mo-1V DA	145,400	131,500	14
Ti-6Al-4V MA	Not available		

Heat Treatment

Ti-8Al-1Mo-1V DA	1450°F, 8 hours, furnace cool + 1450°F, 15 min. AC
Ti-6Al-4V MA	Mill annealed

Note: Information as submitted by supplier
Note: Actual mechanical properties determined in this investigation are shown in Table II

*DA Duplex annealed
**MA Mill annealed

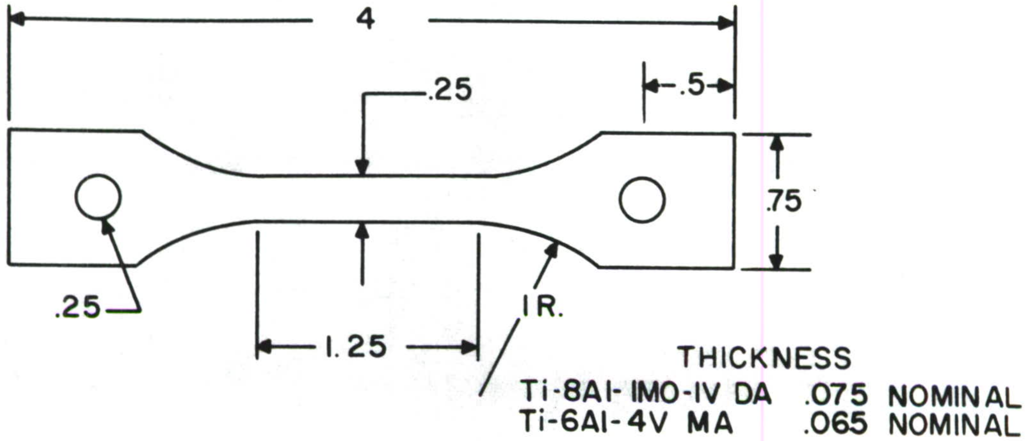


Figure 1. Tensile Specimen

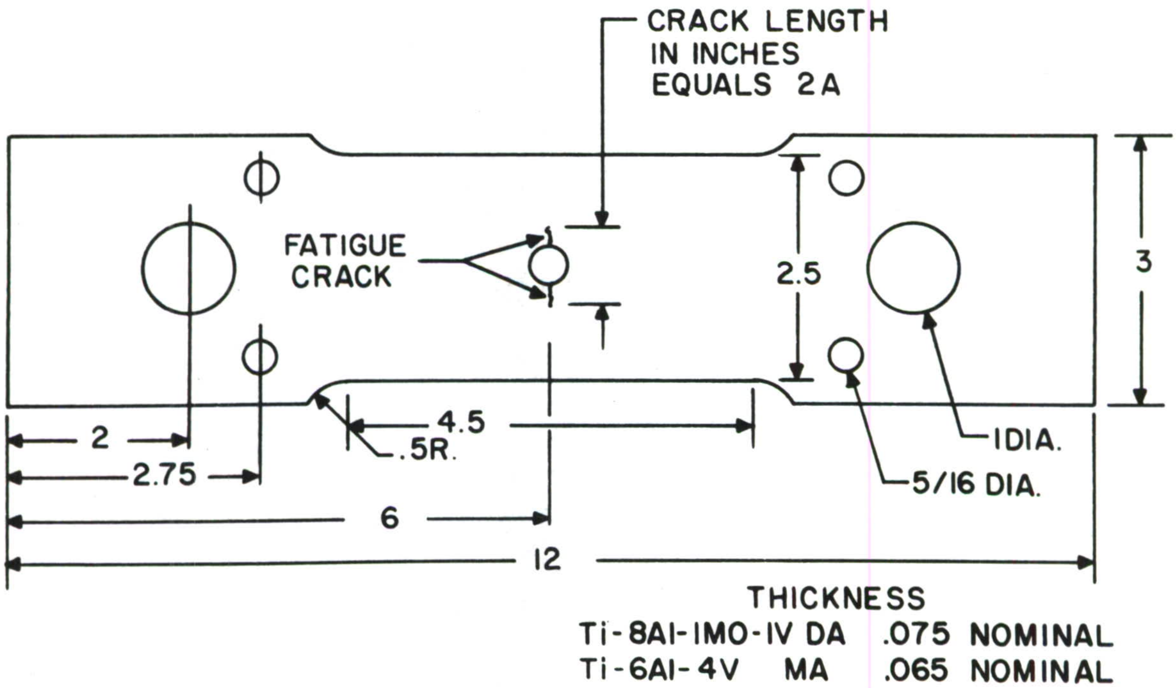
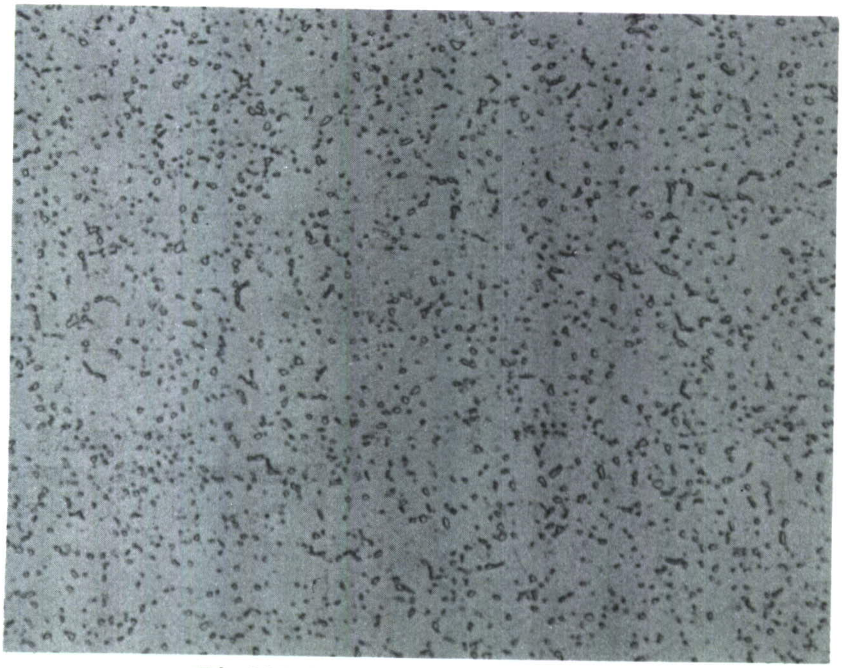
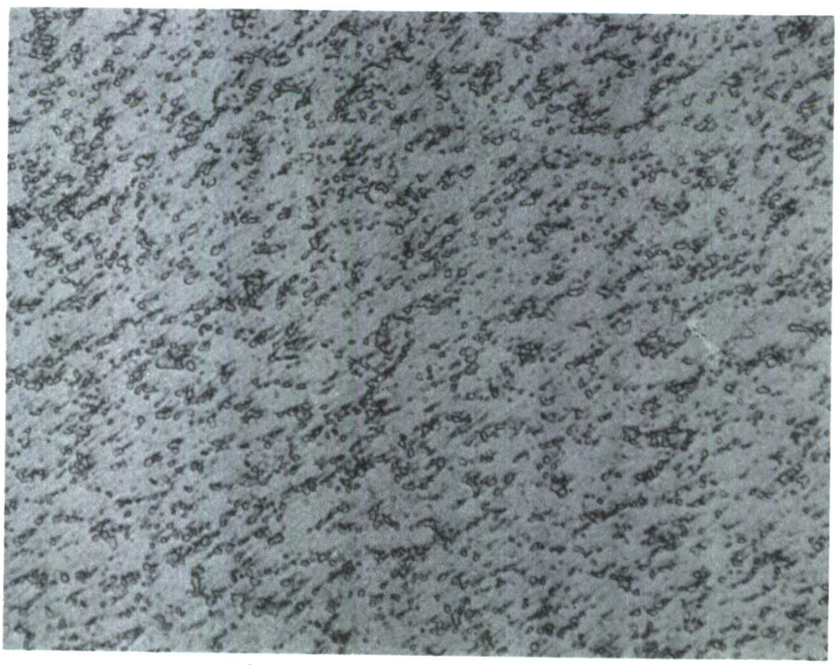


Figure 2. Fracture Toughness and Stress Corrosion Specimen



Ti-8Al-1Mo-1V Duplex Annealed



Ti-6Al-4V Mill Annealed

Figure 3. 500X Photomicrographs of Material Tested

SECTION III

TEST EQUIPMENT

The testing machines utilized included a 12,000 lb capacity Schenck tension-compression fatigue machine with low and high speed loading capibilities (approximately 40 cpm and 1300 to 2000 cpm respectively); a 50,000 lb Wiedemann tensile machine equipped with an automatic cycler for low cycle fatigue testing; a 10,000 lb Instron tensile machine; and a 40,000 lb Baldwin creep testing machine. Typical test set-ups using these machines are shown in Figures 4 through 6.

A Sanborn recorder was used to record load versus time data during low cycle fatigue testing on the Schenck fatigue machine.

A Boyle compliance gage was modified for a three-inch gage length as shown in Figure 7. The increase in gage length was required in order to insert a cup around the specimen to include the induced crack area. See Figure 8. A sufficient quantity of a 3.5 percent NaCl solution was added to the cup to assure that the crack area was totally immersed during the tests. The modified gage was equipped with a two-inch microformer coupled with an Automatic Timing and Controls, Inc. demodulator and a Leeds and Northrup Co. recorder to permit measurement of the deflection within the gage length of the specimen.

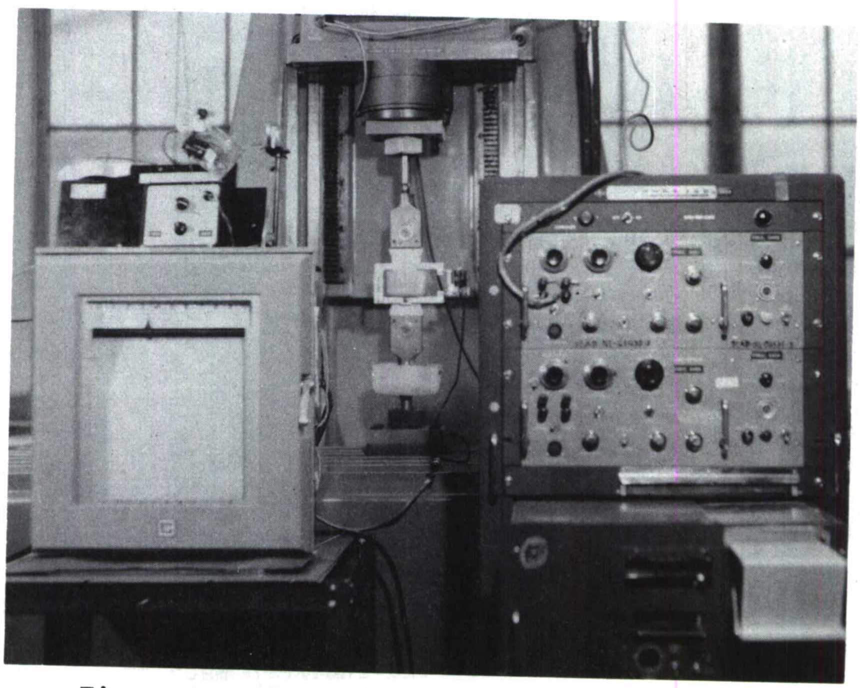


Figure 4. 12,000 lb Schenck Fatigue Machine

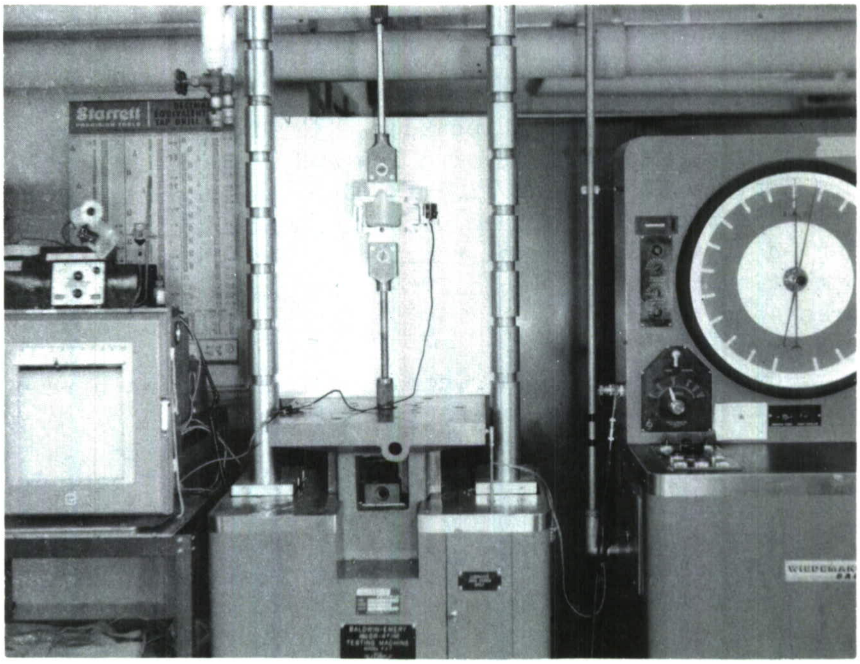


Figure 5. 50,000 lb Wiedemann Tensile Machine

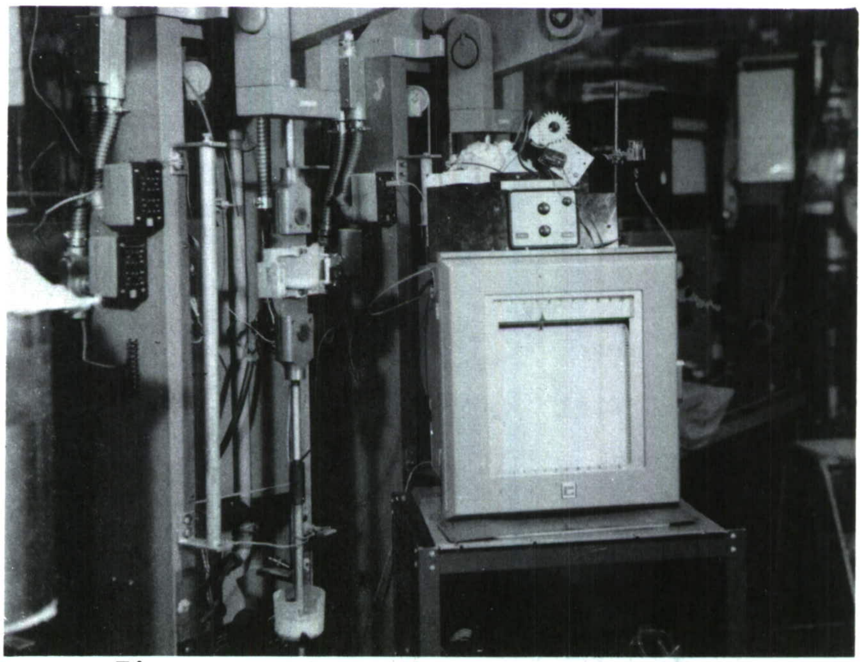


Figure 6. 40,000 lb Baldwin Creep Machine

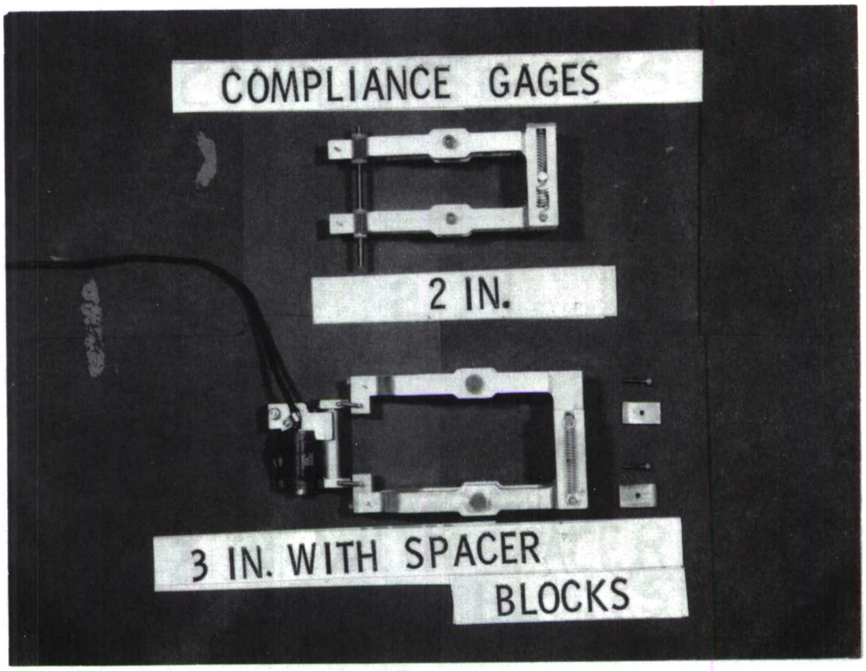


Figure 7. Standard Two-Inch Compliance Gage and Modified Three-Inch Gage

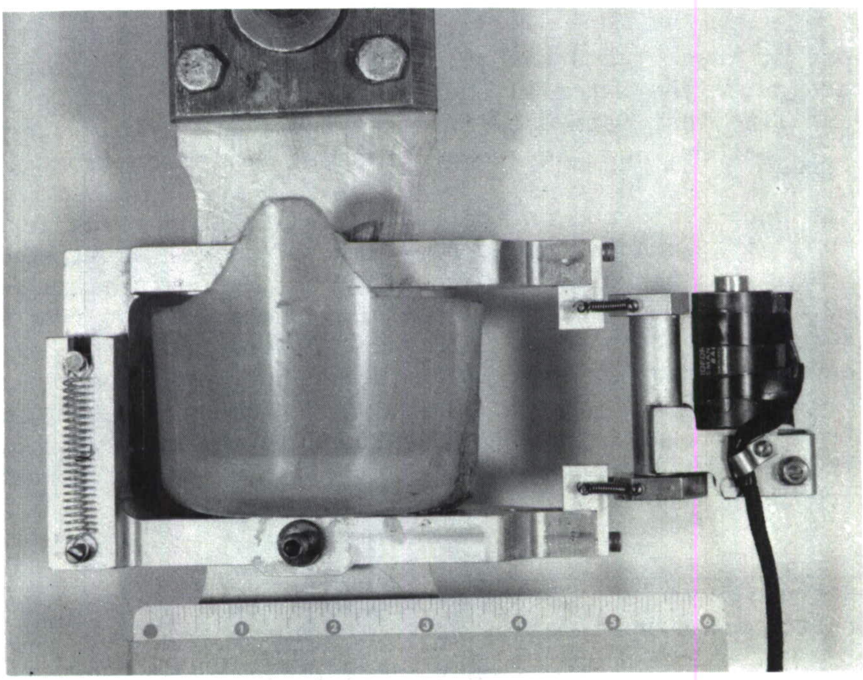


Figure 8. Three-Inch Deflection Gage and Cup on Specimen

SECTION IV

TEST PROCEDURES

CRACK LENGTH CALIBRATION

In order to determine the crack length as a function of time or load cycles it was necessary to perform a special calibration referred to as a displacement calibration technique. A calibration specimen (configuration shown in Figure 2) with a sawed-in crack of known length was loaded in the Instron Tensile machine to a gross stress slightly below the deviation from linearity* (elastic response). The modified three inch compliance gage, previously described, with a magnification of 1000X was used to monitor the deflection in the three-inch gage section. Load versus deflection was continuously recorded on a X-Y recorder. This procedure was continued using the same specimen but with various sawed-in crack lengths. From this calibration a family of load versus deflection curves for various crack lengths was obtained as shown in Figure 9. These curves were then converted to crack length versus deflection for constant load as illustrated in Figure 10. The constant load curves were used to convert deflection versus cycles curves obtained from test data to crack length versus cycles. It should be noted that the maximum calibration load for each sawed-in crack length was selected to be below the deviation from linearity of the material to insure linear elastic response of the specimen and to prevent plastic deformation and crack extension.

BASE LINE DATA TESTS

The purpose of these tests was to obtain basic materials properties data in order to categorize the material and to insure the material met specifications. The base line test data used in this report are: yield strength, stress intensity factors, and the gross stress at deviation from linearity.

These tests were performed on the 50,000 lb Wiedemann tensile machine which is equipped with an autographic recorder. Tensile tests (specimen configuration shown in Figure 1) were run at room temperature utilizing a head speed of 0.05 inches per minute. Fatigue cracks for the fracture toughness specimens (configuration shown in Figure 2) were initiated and extended to approximately 0.8 inches in the 12,000 lb Schenck fatigue machine. The fracture tests were performed in the 50,000 lb Wiedemann. A standard 2 inch Boyle gage with a magnification of 470X was used to determine compliance.** Stress intensity factors (K_c and K_{Ic})*** were calculated by a computer program (see Reference 4).

---

* Deviation from linearity: Point on the load versus deflection curve from a fracture toughness specimen at which the curve becomes nonlinear.

** Compliance: Stiffness; extension to load ratio; used in plane stress fracture toughness tests to determine crack length at onset of catastrophic fracture.

*** K_c: Plane stress stress intensity factor;
K_{Ic}: Plane strain stress intensity factor.

STATIC CRACK GROWTH TESTS

The static environmental crack growth tests were performed to determine whether the titanium alloys in this investigation performed in the same manner as indicated in the literature. Fatigue precracked specimens (one from each alloy under investigation) were loaded in the Baldwin creep machine. The specimens were instrumented with the three-inch deflection gage and a 3.5 percent NaCl solution surrounded the crack area. The static loads used were sufficient to insure gross stresses equal to or greater than the gross stress at deviation from linearity. During these tests deflection versus time was continuously monitored on a L & N recorder.

DYNAMIC CRACK GROWTH TESTS

The dynamic crack growth specimens were tested in the Schenck and Wiedemann testing machines at frequencies of 40 cpm and 2 cpm respectively. The deflection within the three-inch gage section was recorded at a constant stress ratio "R" where $R = \frac{\sigma_{min}}{\sigma_{max}} = 0.1$.

Deflection versus time charts generated from the crack growth tests were used to determine crack length versus cycles by the procedure outlined previously. The total deflection corresponding to the maximum load during the first cycle was the reference point used to determine further crack growth. The crack length at the beginning of the low frequency fatigue was determined by post test inspection of the failed specimens. As a consequence of knowing the initial crack length, deflection, and the corresponding load (for this case the highest load), further deflections were converted to total crack length by means of the calibration curves already determined.

Two specimens of the Ti-8Al-1Mo-1V DA series (D-8 and D-9) which were not used for crack growth tests were used to study fatigue crack initiation in a corrosive environment. In these tests all crack initiation parameters were the same as in the fatigue precracking prior to performing low frequency dynamic crack growth tests except that a corrosive environment (3.5 percent NaCl solution) was added.

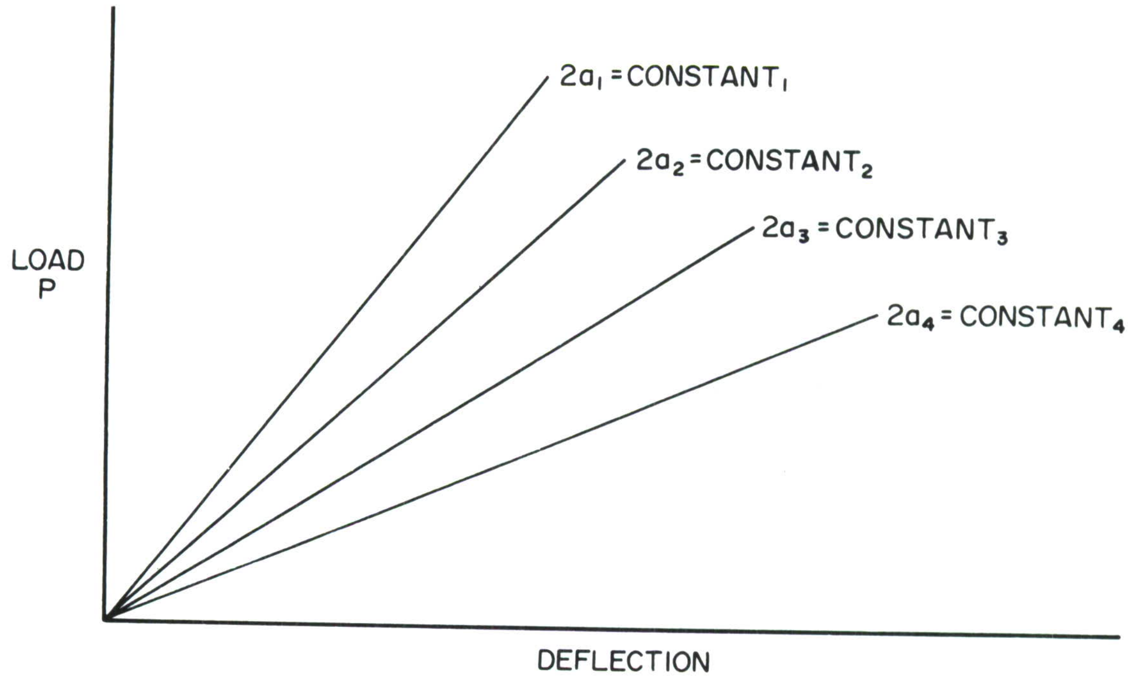


Figure 9. Typical Load vs. Deflection Curves for Various Crack Lengths

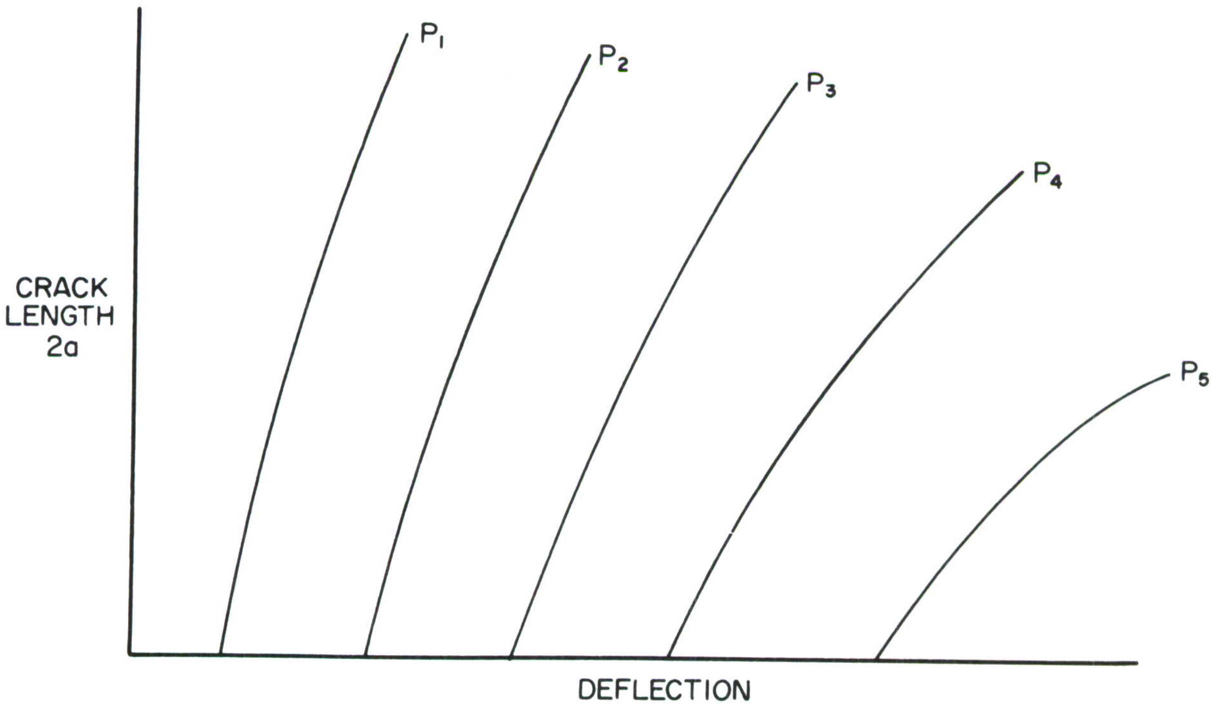


Figure 10. Typical Crack Length vs. Deflection for Various Constant Loads

SECTION V

RESULTS

BASE LINE DATA

The data from the tensile tests are presented in Table II. All tests were run at room temperature. The results are the average of the number of tests indicated.

TABLE II

Tensile Data

Alloy	Ti-8Al-1Mo-1V DA	Ti-6Al-4V MA
Nr. of tests	4	7
σ_{tu}*, KSI	169.7	132.6
σ_{ty}*, KSI	154.1	122.1
%e*	15.6	17.0

Note: *σ_{tu} = ultimate tensile strength

*σ_{ty} = tensile yield strength

*%e: = percent elongation

Fracture toughness test results are presented in Table III. These results are from one test of each alloy.

It should be noted that the only valid use that can be made of the fracture data is to show the approximate toughness of the two materials tested. The plane strain stress intensity factor (K_{nc}), as calculated from the deviation from linearity of the load versus deflection curves, gives only an indication of crack initiation resistance of the material. There was not enough elastic constraint at crack initiation to cause a plane strain "pop-in" condition. Therefore, no distinct "pop-in" was observed. Also, for the plane stress stress intensity factor (K_c), the ratio of the average net section stress to the tensile yield stress greatly exceeds the 0.8 upper limit (Reference 5) for accurate plane stress measurement.

TABLE III

Fracture Data

Alloy	Ti-8Al-1Mo-1V DA	Ti-6Al-4V MA
2a initial, inches	.851	.835
2a final, inches	1.387	1.34
Gross stress for K_{nc}*, KSI	36.49	37.9
Net stress ratio for K_{nc}	.42	.47
Net stress ratio for K_c	1.33	1.43
Plastic zone correction, inches	.0193	.0247
K_{nc} basic, KSI $\sqrt{IN.}$	44.4	45.6
K_c* basic, KSI $\sqrt{IN.}$	134.2	132.9

*K_{nc}: plane strain stress intensity factor computed from deviation from linearity.

*K_c: plane stress stress intensity factor

STATIC CRACK GROWTH DATA

One specimen from both the Ti-8Al-1Mo-1V DA and Ti-6Al-4V MA sheets was tested to obtain the data shown in Figure 11 in the Appendix. The gross stresses these specimens were able to sustain for a considerable period of time were well above the deviation from linearity for both materials (36.49 KSI for Ti-8Al-1Mo-1V and 37.9 KSI for Ti-6Al-4V). A literature search indicated titanium alloys undergo their greatest degradation of properties in the first hour or less (See References 1, 2, 3). Reference 2 indicates that at a gross stress of 50 KSI Ti-8Al-1Mo-1V DA specimens should fail in one hour. Crack length versus time was not plotted because the crack length determination calibration is not accurate above the deviation from linearity. It is only accurate in the elastic compliance range of a material.

DYNAMIC CRACK GROWTH DATA

Dynamic crack growth curves for Ti-6Al-4V MA are presented in Figure 12 to 15. Each curve represents the results of one specimen test. The curves are labeled with the appropriate gross stress, environment, and frequency of fatigue. The pH of the salt solution, when indicated, was 6.6 to 6.8. The initial crack length of each specimen in Figures 12 to 15 was not identical. Therefore, the curves of Figures 12, 13, and 14 were shifted horizontally as shown in Figures 16, 17, and 18 to begin all crack-growth curves with an initial crack length of 0.85 inch. The curve for specimen E-7 in Figure 15 was not altered because it had an initial crack length of 0.85 inch. The curves were shifted to the same initial crack length to present a comparison of the crack growth as a function of the various parameters (frequency and environment). A composite plot of selected curves from Figure 15, 16, 17, and 18 is presented in Figure 19. When two specimens were tested at one load level and environment, the average of the two curves was plotted in Figure 19. The form of curve F-8 is questionable because of the limited number of test data points. Therefore, the lower portion of curve F-8 on Figure 19 was adjusted to follow the general form of curves E-8, F-10 and F-13. Figure 20 was obtained by plotting the maximum gross stress values from static and dynamic tests versus the corresponding crack propagation life. Inasmuch as the data on Figure 20 was obtained at a test frequency of 40 cpm, the data from Specimen E-10 (tested at 2 cpm) was not included. Thus, Figure 20 contains two "S-N curves" for representing the low frequency fatigue crack propagation life of Ti-6Al-4V MA.

Crack length versus cycle curves for the Ti-8Al-1Mo-1V DA are presented in Figure 21 for one gross stress level (32 KSI). The curves of Figure 21 were shifted horizontally in Figure 22 to begin all crack-growth curves with an initial crack length of 0.85 inch just as the curve of the Ti-6Al-4V MA were shifted. Again, this was done to present a comparison of the relative crack growth as a function of the various parameters (frequency and environment).

The results of the corrosive fatigue crack initiation tests are presented in Table IV along with the data obtained from air-environment fatigue precracking exercises. The precrack lengths were measured optically directly from the specimen.

TABLE IV

Crack Initiation Data for Ti-8Al-1Mo-1V DA*

Specimen	Environment	Max. Gross Stress (KSI)	Cycles to Initiate and Propagate Crack	Precrack Length (inches)
C-3	Air	25	51,800	0.82
C-8	Air	25	32,900	0.79
D-6	Air	25	25,000	0.78
D-7	Air	25	23,000	0.85
D-8	NaCl	25	10,000	0.80
D-9	NaCl	25	15,400	1.20

*Data in this Table for air environment specimens were obtained from fatigue precracking of crack growth specimens.

SECTION VI

DISCUSSION AND ANALYSIS

Ti-6Al-4V MILL ANNEALED SPECIMENS

Referring to Figures 15 to 19, nothing unusual is observed except for the curve of crack growth of specimen E-10 in Figure 16. This specimen was tested at a frequency of two cpm and had a longer fatigue life than the specimen run at 40 cpm in the same NaCl environment. At all stress levels, the specimens tested in the salt solution failed in fewer cycles than corresponding specimens run in air. Specimens which had an initial unsymmetrical fatigue crack (cracks that grew asymmetrically with respect to the center line of the specimen) initially reacted as if the crack was symmetric. But, as the crack grew toward instability the unsymmetrical cracks grew faster than the symmetrical cracks.

Specimen E-10 was tested at the two cpm loading rate to determine what parameters contributed to the reduction of cyclic life in the corrosive environment. For example, if the cyclic life was exposure time dependent specimens E-9 (40 cpm) and E-10 (2 cpm) would have failed in the same amount of time and E-10 would have failed at 1/20th of the number of cycles of E-9.

If the cyclic life was dependent on the number of cycles to failure, both specimens would have lasted an equal number of cycles and E-10 exposure time would have been 20 times longer than E-9.

Based on the test results obtained E-10 (2 cpm) lasted 41 times longer and required approximately 3 times as many cycles to reach the equivalent crack length of E-9 (40 cpm). This suggests a complex frequency dependent relationship with lower frequencies requiring more load cycles to fail the specimen. Of course, this is the result of only one test, but it is further substantiated in the tests of the Ti-8Al-1Mo-1V DA which are discussed later in this section.

In attempting to determine the final mode of failure (the onset of catastrophic crack growth) the final (critical) values of the stress intensity factors and the net stress were calculated. The crack length prior to final failure was determined by visual inspection of the fracture faces. The area of the fracture faces where low cycle fatigue had caused slow crack growth was different from either the high cycle fatigue area of the fatigue pre-cracking or the catastrophic area of fracture. Results of the inspection and calculation are presented in Table V. From Table V it can be seen that the final critical stress intensity factor is not equal to either the K_{nc} of K_c value (46 and 133 KSI $\sqrt{IN}$. respectively, obtained statically) of the material. Since the net stress at failure was approximately equal to the ultimate strength of the material (132.6 KSI from tensile tests) the specimens probably failed from overload and not because of crack sensitivity.

TABLE V

Final Crack Length Data for Ti-6Al-4V MA

Specimen	Environment	σ_g max KSI	2a final IN.		K_{CD}* KSI$\sqrt{IN}$	σ_{nc}* KSI
E-8	Air	27	2.01			
E-9	NaCl	27	2.00	2.013	75	136
E-10	NaCl	27	2.03			
F-7	NaCl	28.6	1.85	us. crack		
F-8	Air	28.6	2.00	1.975	76	133
F-11	NaCl	28.6	1.95			
F-10	Air	31.4	1.95			
F-12	NaCl	31.4	1.92	1.93	81	137
F-13	Air	31.4	1.92			
E-7	NaCl	32	1.86	1.89	80.5	132
E-6	Air	32	1.92			

*K_{CD}: Critical dynamic stress intensity factor

*σ_{nc}: Net critical stress

Ti-8Al-1Mo-1V DUPLEX ANNEALED SPECIMENS

Crack growth tests of the Ti-8Al-1Mo-1V DA specimens were primarily oriented toward evaluation of the frequency relationship observed in specimens E-9 and E-10 of the Ti-6Al-4V MA series of tests. An inspection of the curves in Figure 22 indicates the same general trend as was noticed in the previously described Ti-6Al-4V MA curves. Dynamic environmental crack growth was much faster in the 3.5 percent NaCl solution than in the air environment for the same loading rate. Again, the lower cyclic rate (2 cpm) caused an increase in the number of cycles to failure for the same stresses in the corrosive environment tests.

Final critical crack lengths for the Ti-8Al-1Mo-1V DA specimens were scattered and questionable and therefore are not presented. The longest length was 2.05 inches and the shortest (neglecting specimen C-6 which had an unsymmetrical fatigue crack) was 1.84 inches. Because of the scattered final crack length values subsequent calculations of the critical stress intensity factors and the critical net stress values were not made.

Referring to Table IV it will be observed that the number of cycles to initiate and grow a crack to some predetermined length is considerably reduced in a salt solution. Three possibilities exist for this phenomenon. Either the initiation time is reduced, the propagation time is reduced, or both are reduced. The possibility of the reduction being restricted solely to initiation time cannot exist, since all previous data presented for propagation have shown a reduction in cyclic life in a salt solution as opposed to an air environment.

From Figure 22 it can be observed that the propagation time in a salt solution compared to an air environment is reduced by a factor approximately equal to five for a constant frequency. With this factor of five in mind, it is possible that the initiation time of a crack under cyclic loading is the same for the two environments and only the propagation time is changed. Not enough data are available to make a definite statement concerning the fatigue crack initiation in a salt solution. All that can be said is that the combined initiation and propagation time is reduced.

SECTION VII

CONCLUSIONS

1. Dynamic crack growth resistance of the titanium alloys tested is reduced in a NaCl solution as compared to an air environment.

2. The cyclic life of titanium alloys under dynamic loading in a corrosive environment is dependent on the frequency of cycling with lower frequencies causing longer cyclic life on both a time and a cycles to failure basis.

3. More effort is required to obtain conclusive data on the effect of cyclic frequency on crack propagation of titanium in an aqueous medium.

SECTION VIII

REFERENCES

1. B. F. Brown, "A New Stress-Corrosion Cracking Test Procedure for High-Strength Alloys." Paper presented at Sixty-Eighth Annual Meeting of the American Society for Testing and Materials, June 1965.

2. I. E. Figge, "Preliminary Investigation of Fatigue Crack Propagation and Delayed Failure of Titanium and Stainless-Steel Alloys in Aqueous Environments." Paper presented at Workshop on Aqueous Stress-Corrosion Cracking and Corrosion Fatigue of Titanium Alloys, September 1965.

3. B. F. Brown, B. W. Forgeson, T. J. Lennox, Jr., T. C. Lupton, R. L. Newbegin, M. N. Peterson, J. A. Smith, and L. J. Waldron, "Marine Corrosion Studies," Third Interim Report of Progress, NRL Memorandum Report 1634, July 1965.

4. S. O. Davis, N. G. Tupper, D. C. LaGrone and R. M. Niemi, "Center Notched Plane Strain K_{Ic} Fracture Toughness Properties of Several High-Strength Steel Alloys," AFML-TR-65-214, October 1965.

5. J. E. Srawley and W. F. Brown, Jr., "Fracture Toughness Testing," NASA TN D-2599, January 1965.

SECTION IX

APPENDIX

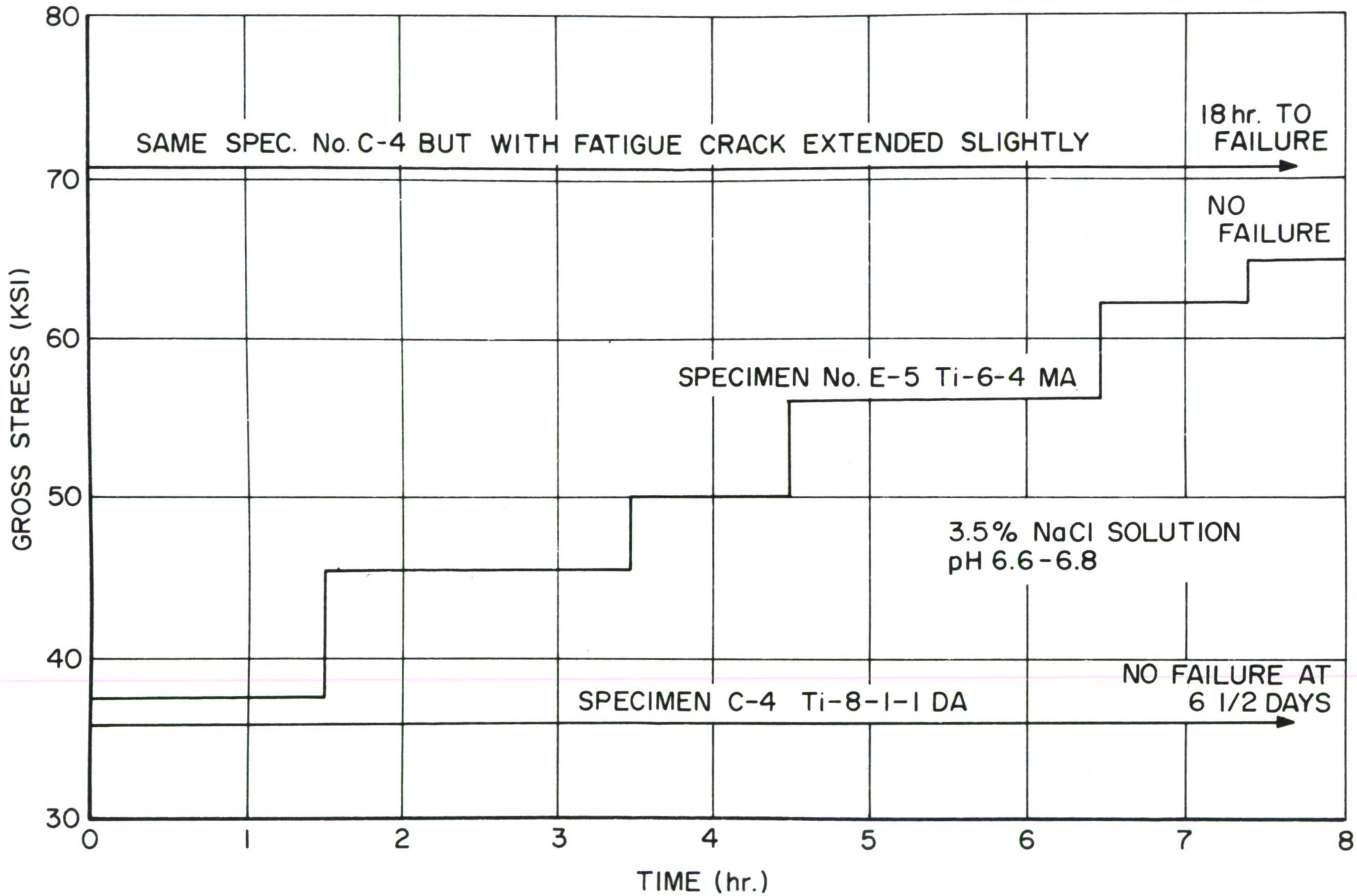


Figure 11. Static Crack Growth Tests for Ti-8Al-1Mo-1V DA & Ti-6Al-4V MA

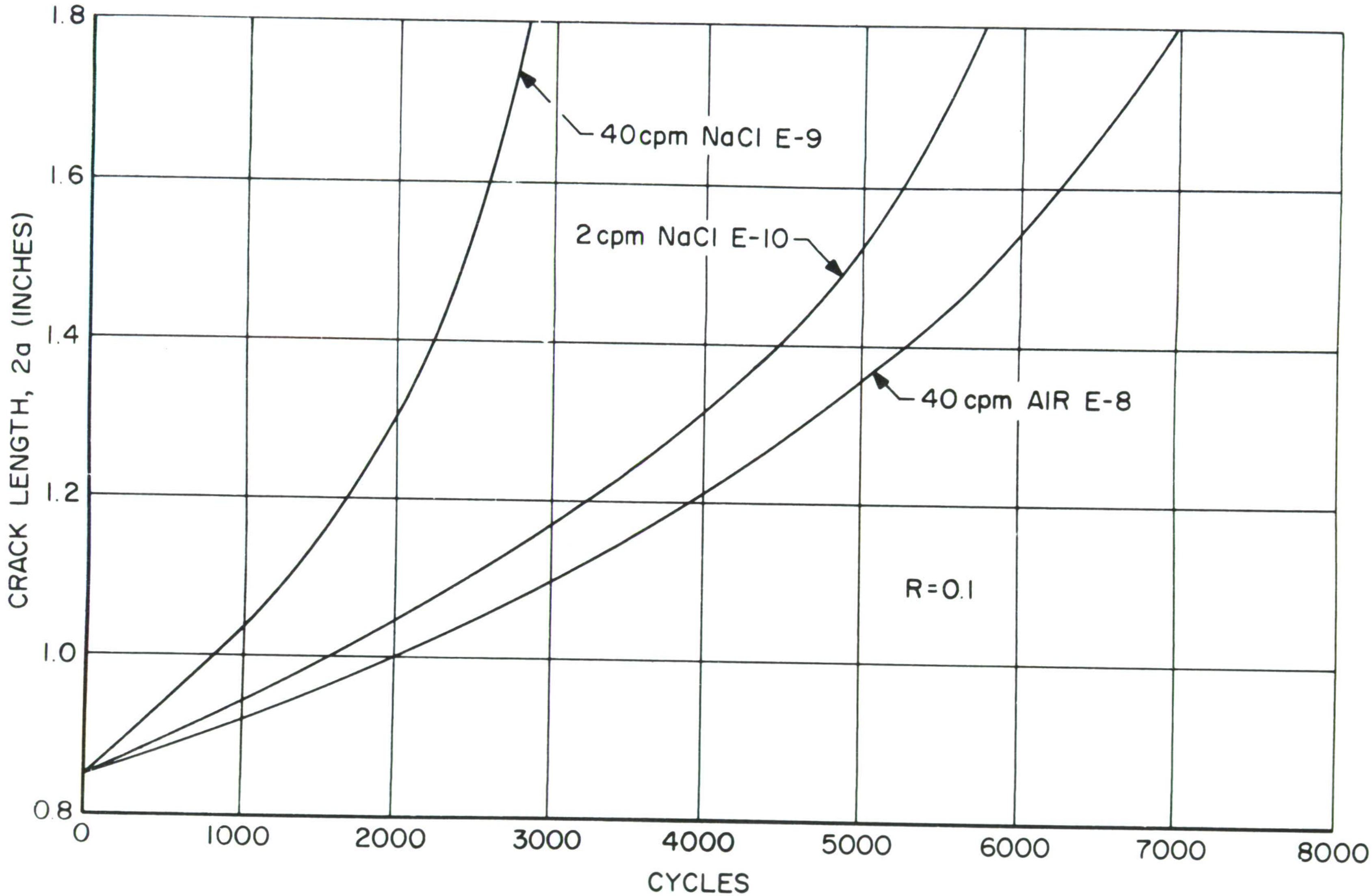
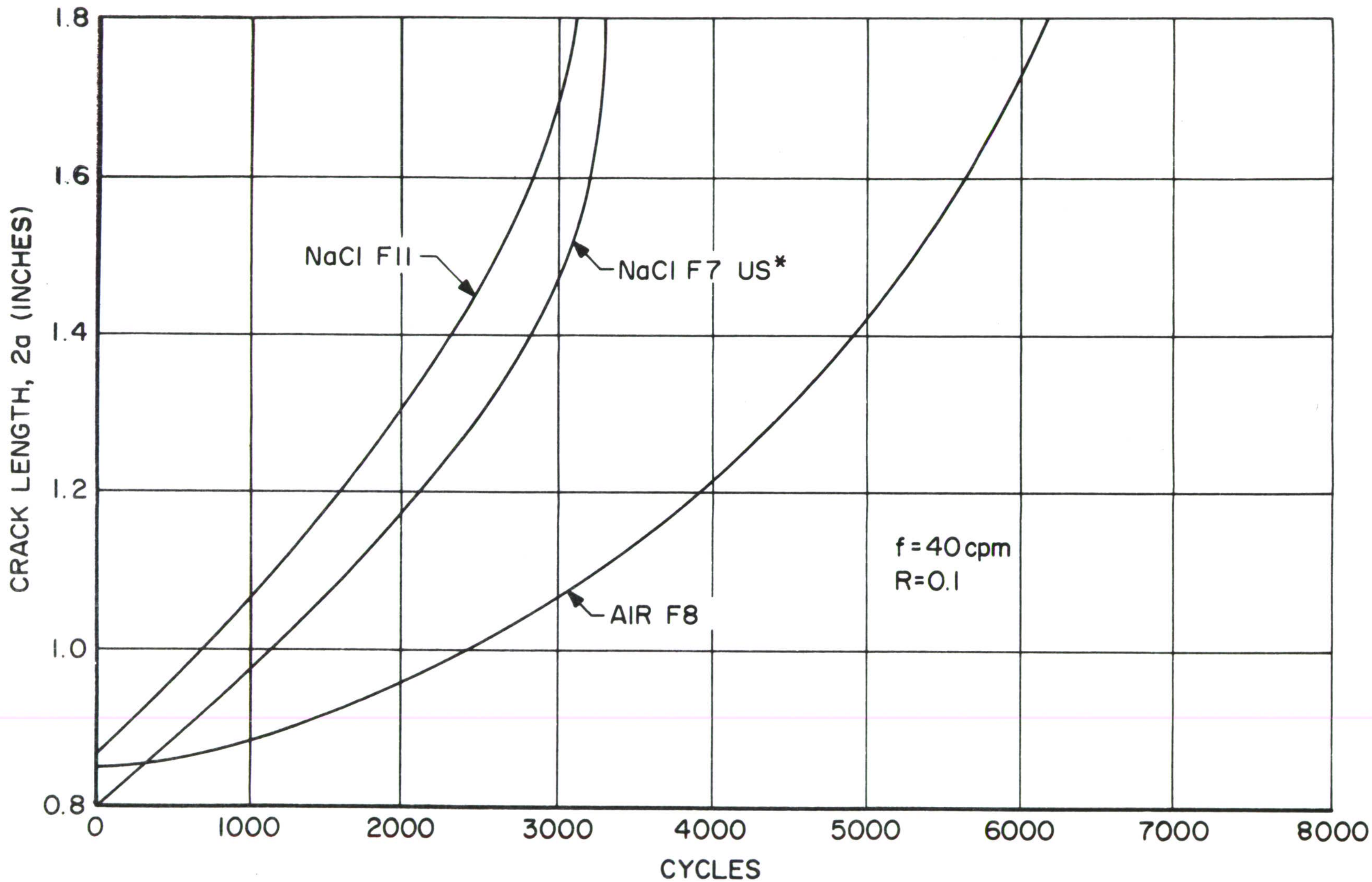


Figure 12. Crack Length vs. Cycles for Ti06Al-4V MA at 27 KSI



*US - UNSYMETRICAL CRACK

Figure 13. Crack Length vs. Cycles for Ti-6Al-4V MA at 28.6 KSI

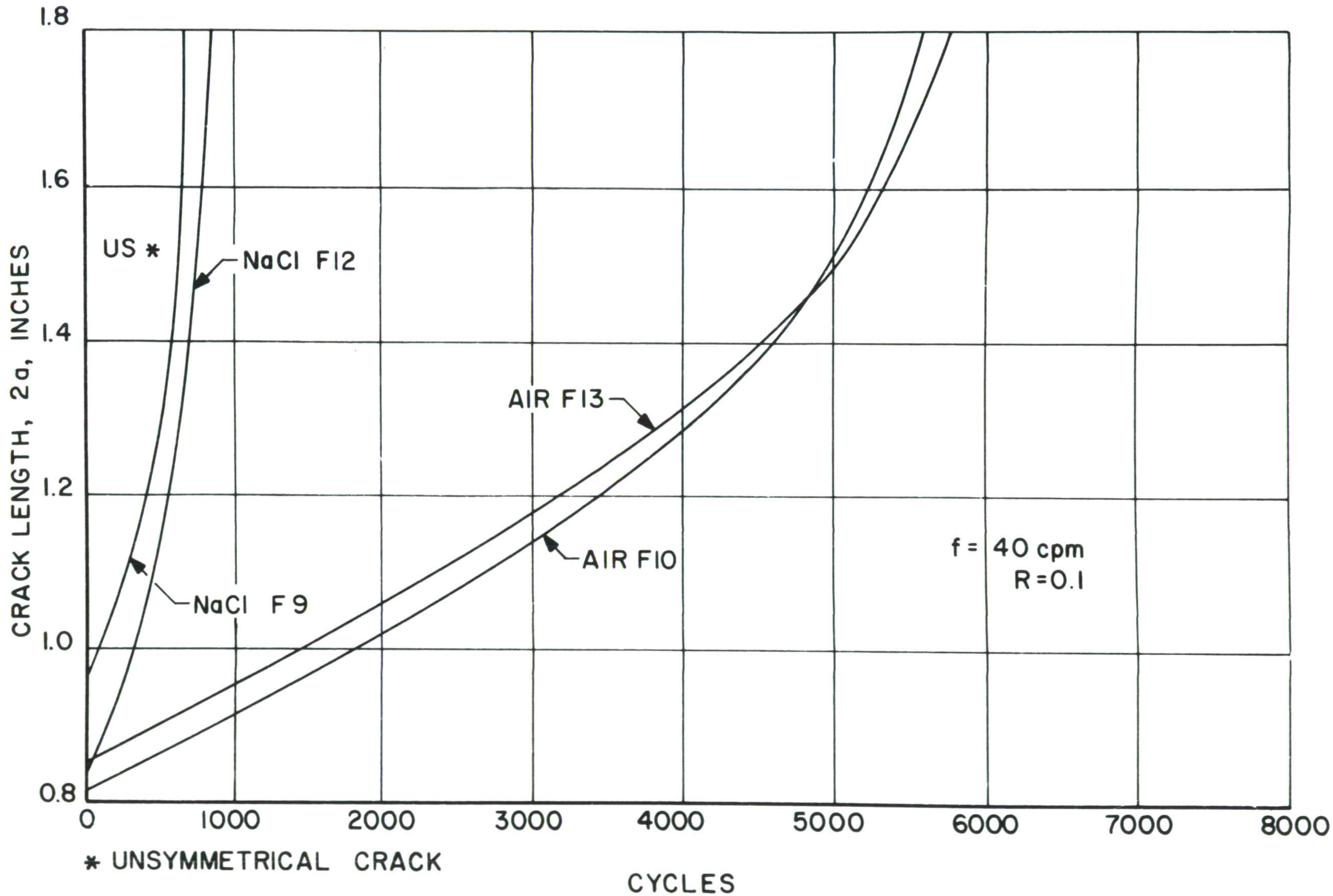


Figure 14. Crack Length vs. Cycles for Ti-6Al-4V MA at 31.4 KSI

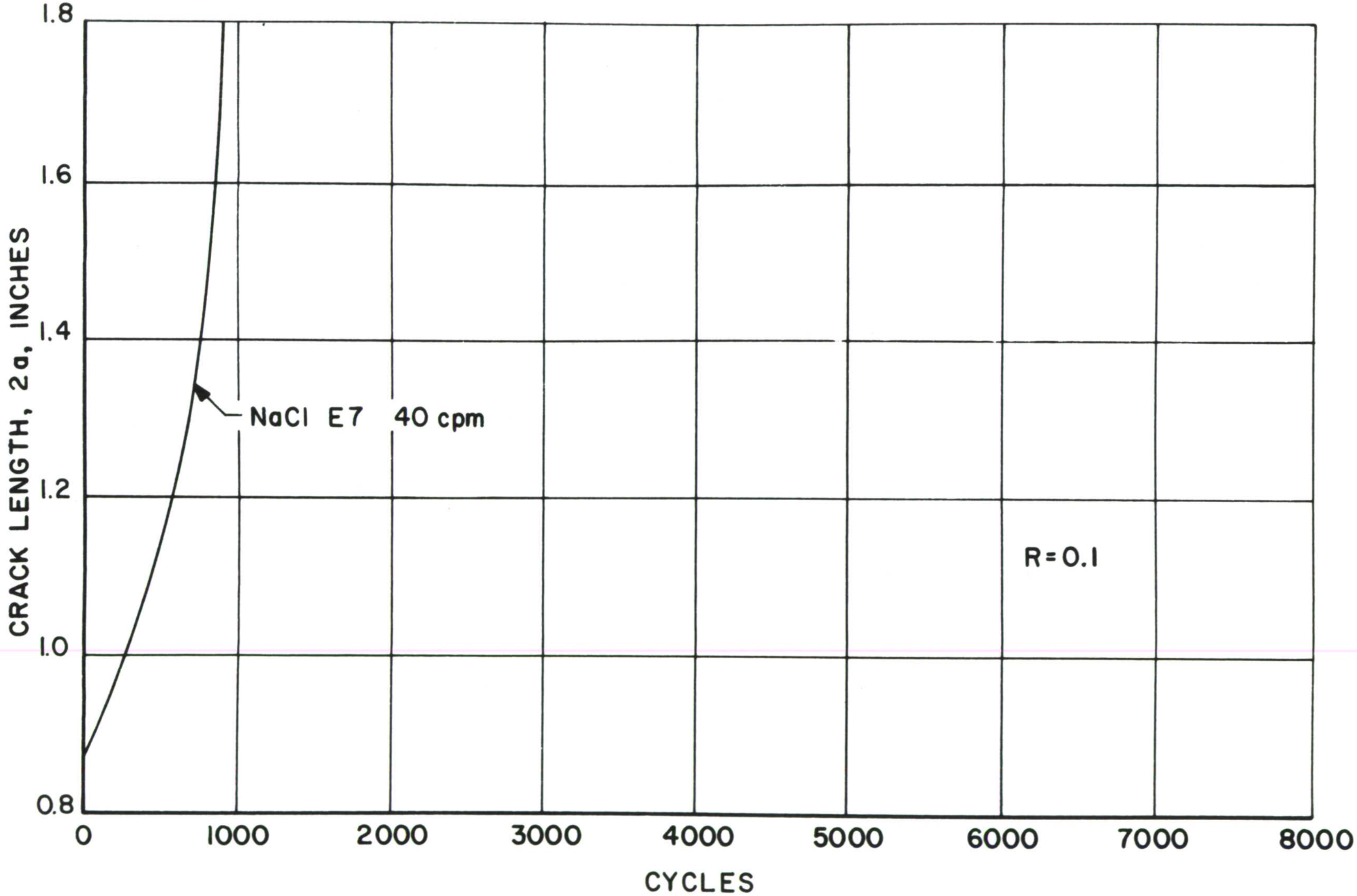


Figure 15. Crack Length vs. Cycles for Ti-6Al-4V MA at 32 KSI

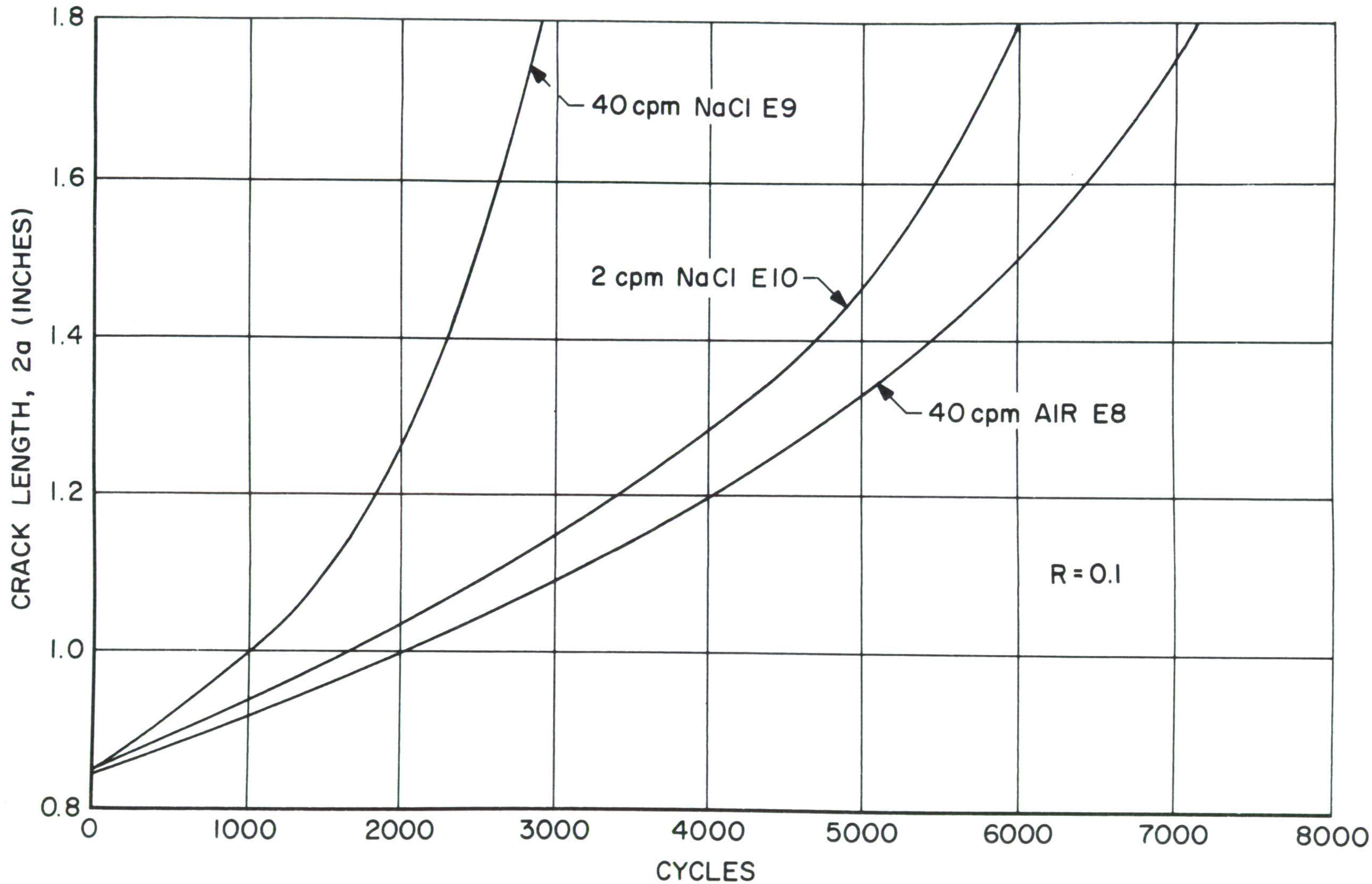


Figure 16. Crack Length vs. Cycles for Ti-6Al-4V MA at 27 KSI for Corrected Initial Crack Length of 0.85 IN.

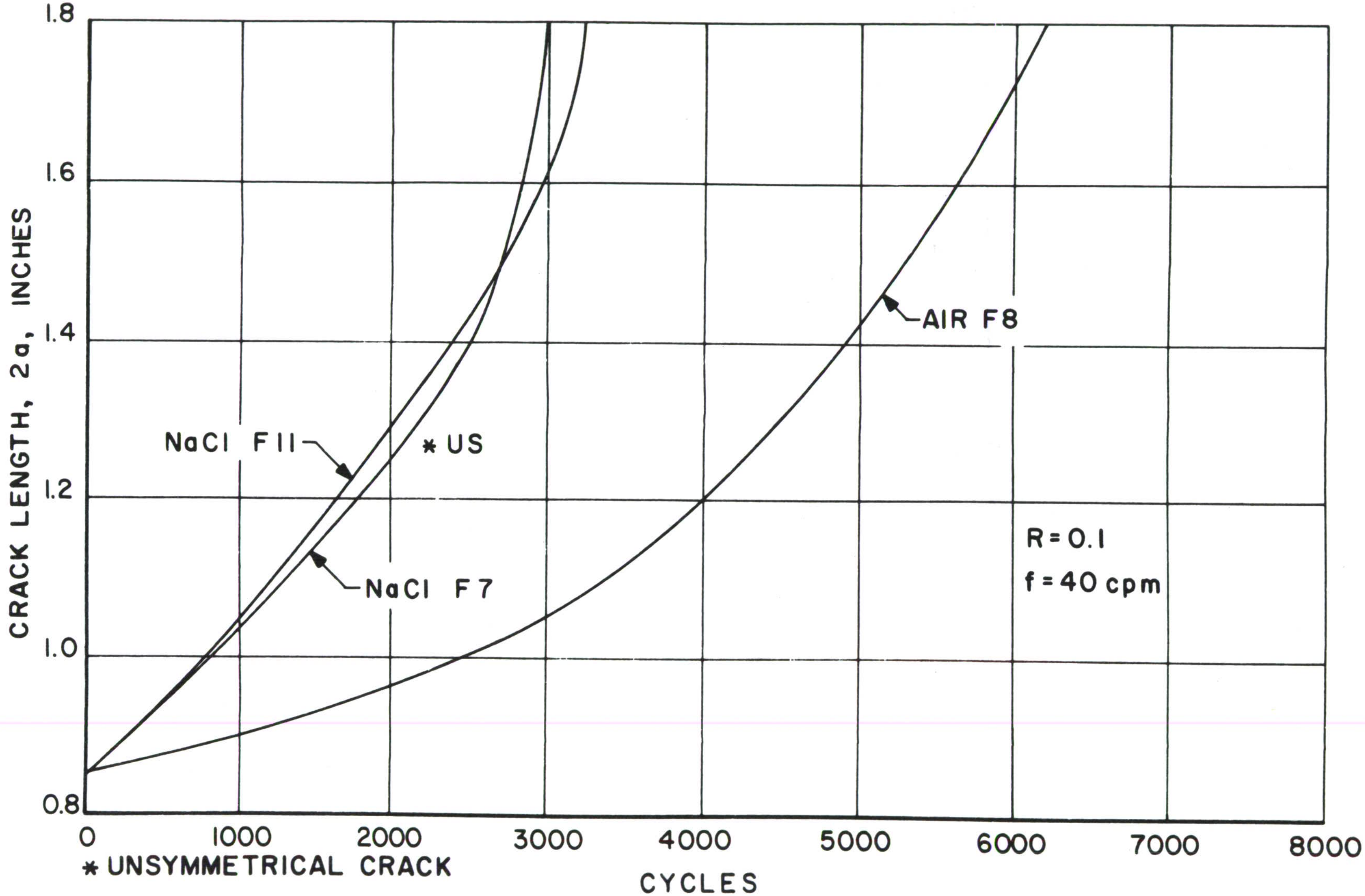


Figure 17. Crack Length vs. Cycles for Ti-6Al-4V MA at 28.6 KSI for Corrected Initial Crack Length of 0.85 IN.

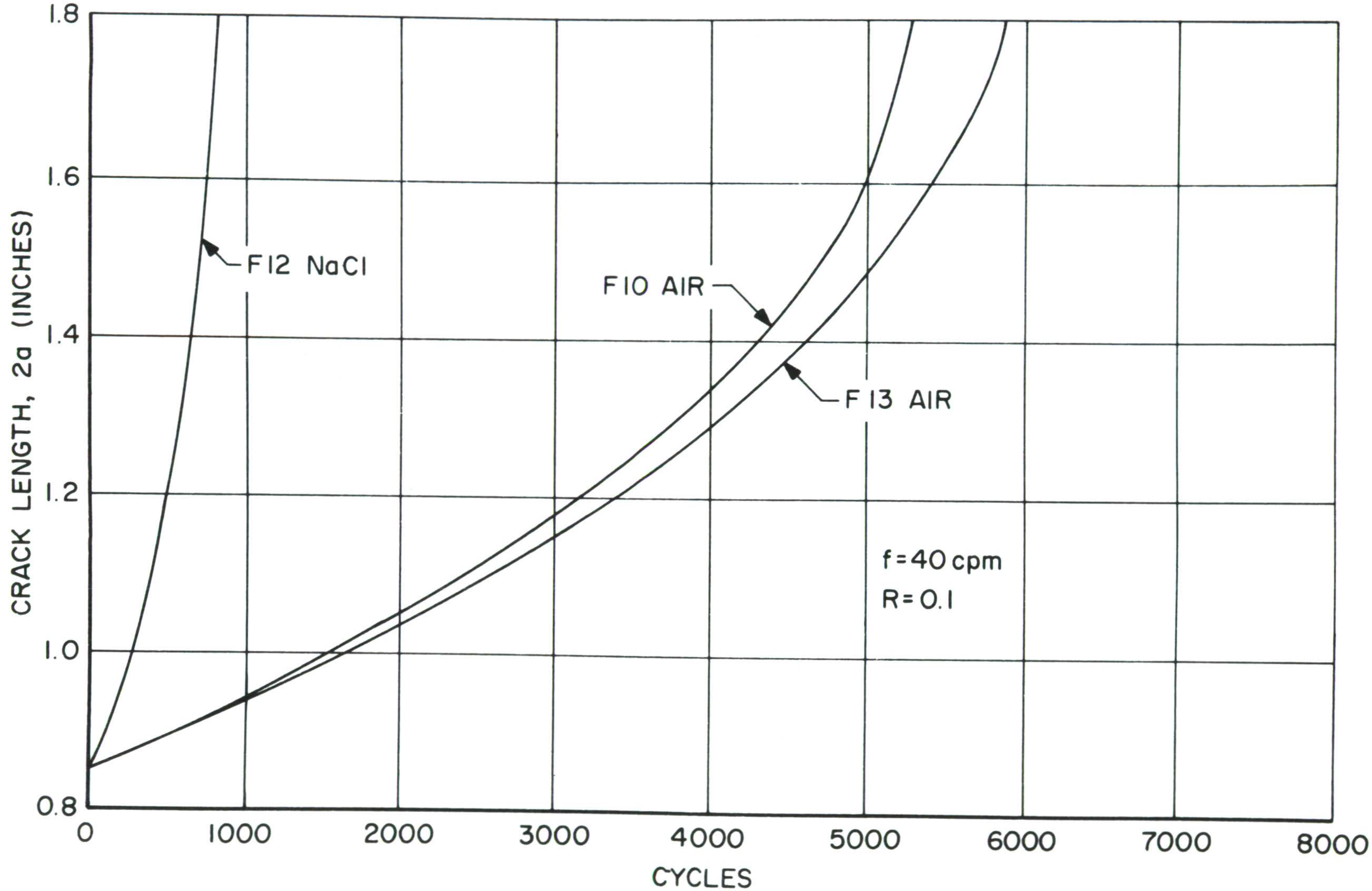


Figure 18. Crack Length vs. Cycles for Ti-6Al-4V MA at 31.4 KSI for Corrected Initial Crack Length of 0.85 IN.

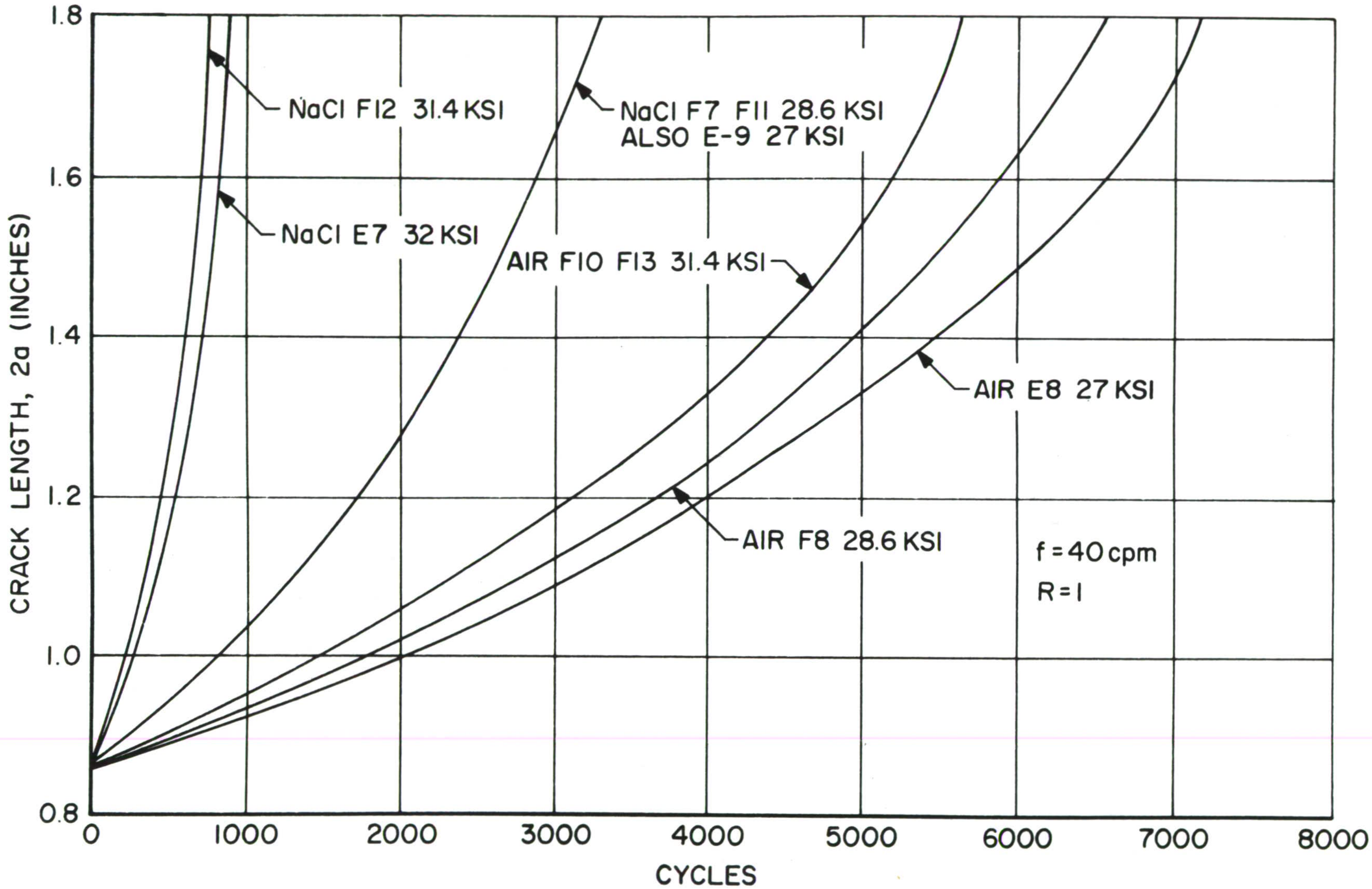


Figure 19. Crack Length vs. Cycles for Ti-6Al-4V MA for Corrected Initial Crack Length of 0.85 IN.

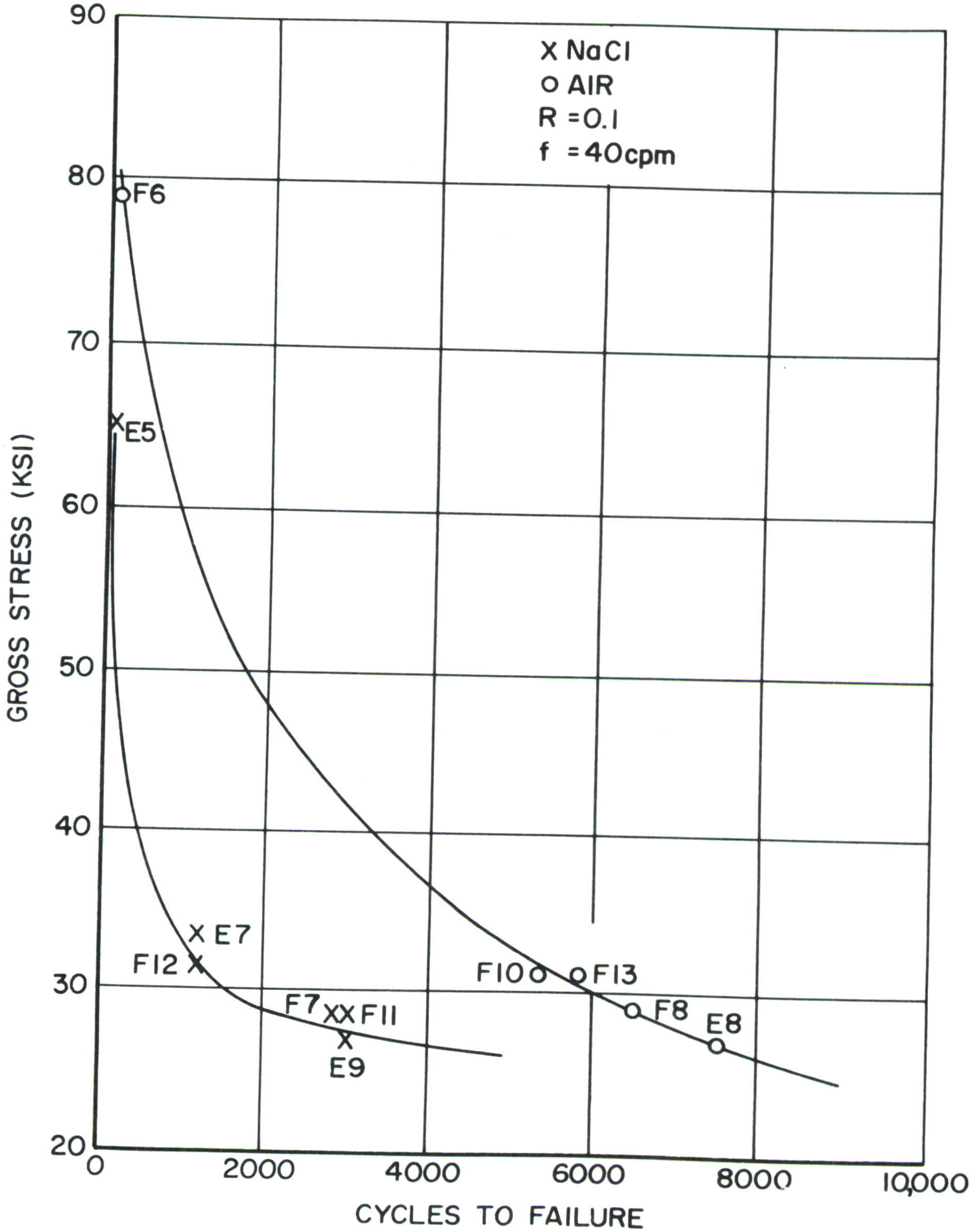
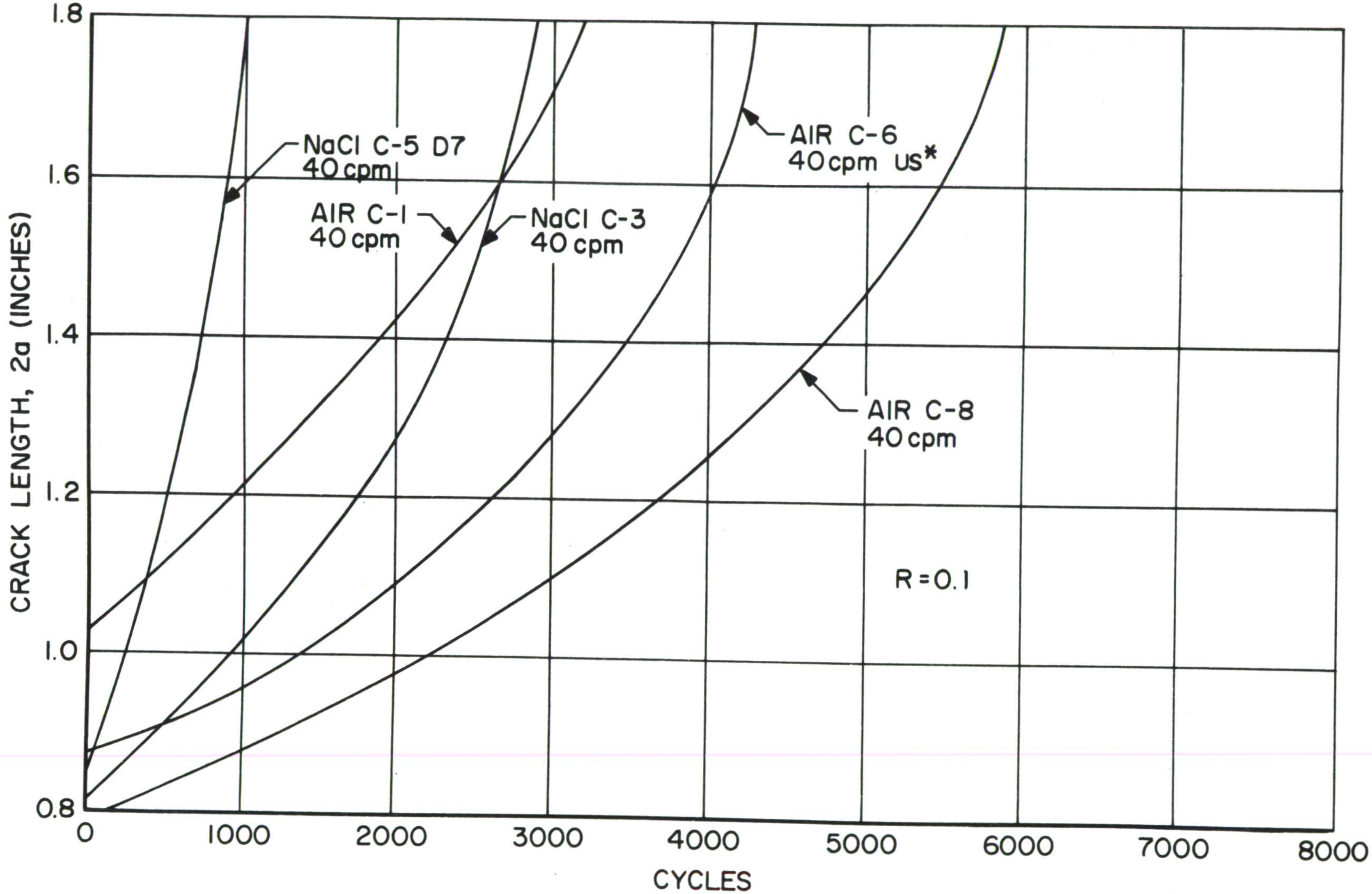
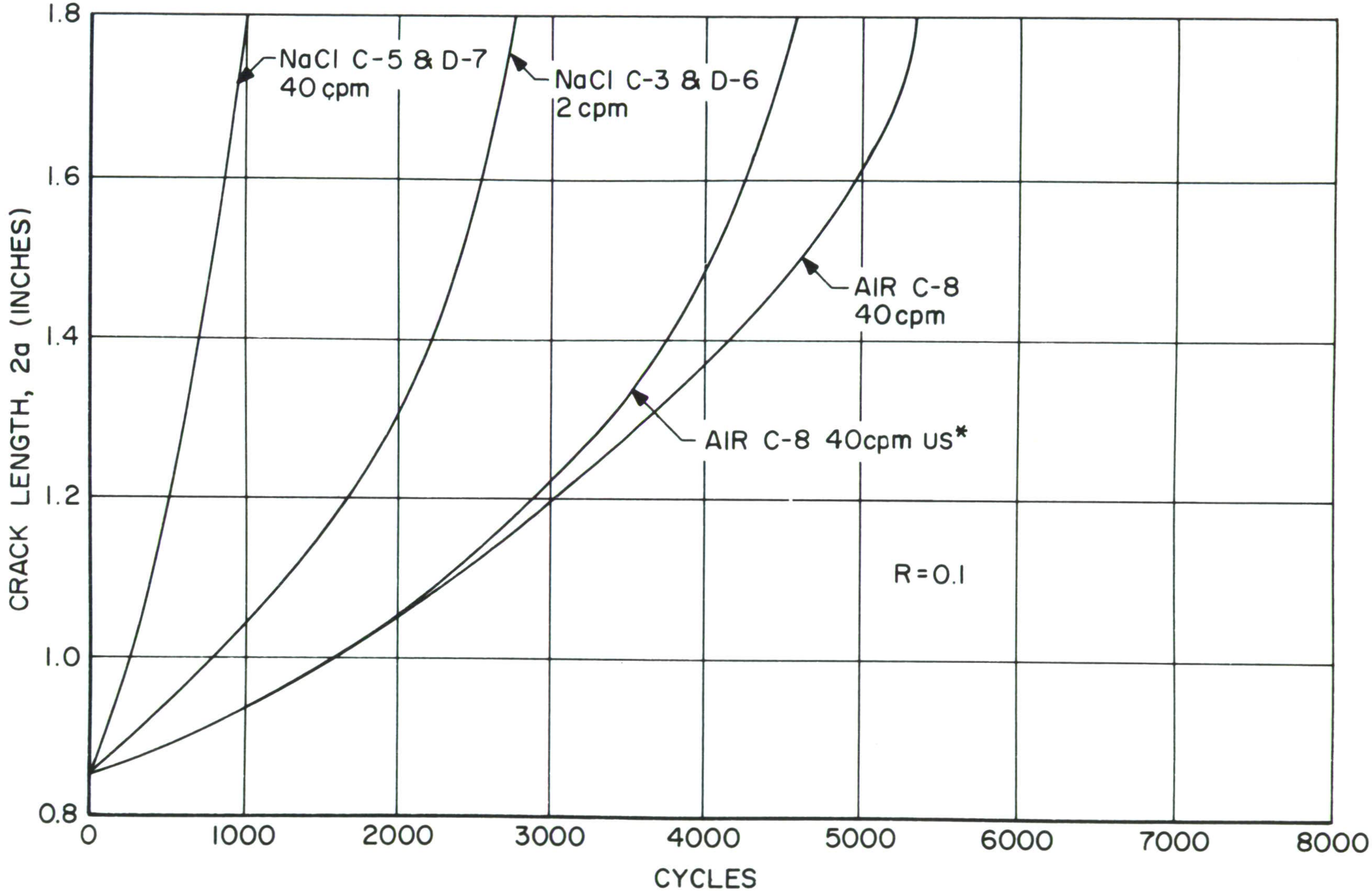


Figure 20. Gross Stress vs. Cycles to Failure for Ti-6Al-4V MA



*US -UNSYMMETRICAL CRACK

Figure 21. Crack Length vs. Cycles for Ti-8Al-1Mo-1V DA at 32 KSI



*US -UNSYMMETRICAL CRACK

Figure 22. Crack Length vs. Cycles for Ti-8Al-1Mo-1V DA at 32 KSI for Corrected Initial Crack Length of 0.85 IN.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

University of Dayton
Research Institute
Dayton, Ohio 45409

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Dynamic Subcritical Crack Growth Properties of Duplex Annealed Ti-8Al-1Mo-1V and Mill Annealed Ti-6Al-4V in an Air and Corrosive Environment

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report, July 1965 to March 1966

5. AUTHOR(S) (Last name, first name, initial)

Petrak, Gerald J.

6. REPORT DATE

January 1967

7a. TOTAL NO. OF PAGES

38

7b. NO. OF REFS

5

8a. CONTRACT OR GRANT NO.

AF 33(615)-1312

b. PROJECT NO. 7381

c. Task No. 738106

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

AFML-TR-66-392

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

None

10. AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Air Force Materials Laboratory, Materials Applications Division (MAAM), Wright-Patterson Air Force Base, Ohio 45433.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Air Force Materials Laboratory
Research and Technology Division
Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This program was conducted to determine the dynamic (fatigue) crack growth properties of two titanium alloys (Ti-8Al-1Mo-1V Duplex Annealed and Ti-6Al-4V Mill Annealed) at room temperature in an air and in a 3.5 percent NaCl environment. Dynamic crack growth versus cycles to failure was determined at two loading frequencies (40 cpm and 2 cpm) for the corrosive environment and at a 40 cpm loading frequency for the air environment. A comparison of the air and corrosive environment test data at the 40 cpm loading frequency shows a reduction in cyclic life when exposed to the 3.5 percent NaCl environment. Also a comparison of the corrosive environment test data at loading frequencies of 40 cpm and 2 cpm shows a reduction in cyclic life on both a time and a number of cycles to failure basis at the higher loading frequency.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.